

NGC 3147: a “true” Seyfert 2 without the broad-line region

S. Bianchi^{1*}, A. Corral², F. Panessa², X. Barcons², G. Matt¹, L. Bassani³,
F.J. Carrera², E. Jiménez-Bailón^{4,5}

¹*Dipartimento di Fisica, Università degli Studi Roma Tre, via della Vasca Navale 84, 00146 Roma, Italy*

²*Instituto de Física de Cantabria (CSIC-UC), 39005 Santander, Spain*

³*INAF-IASF, Via P. Gobetti 101, 40129 Bologna, Italy*

⁴*Instituto de Astronomía, Universidad Nacional Autónoma de México, Apartado Postal 70-264, 04510 Mexico DF, Mexico*

⁵*LAEFF Apd. 78 Villanueva de la Cañada - 28691-Madrid, Spain*

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ABSTRACT

We report on simultaneous optical and X-ray observations of the Seyfert galaxy, NGC 3147. The XMM-*Newton* spectrum shows that the source is unabsorbed in the X-rays ($N_H < 5 \times 10^{20} \text{ cm}^{-2}$). On the other hand, no broad lines are present in the optical spectrum. The origin of this optical/X-rays misclassification (with respect to the Unification Model) cannot be attributed to variability, since the observations in the two bands are simultaneous. Moreover, a Compton-thick nature of the object can be rejected on the basis of the low equivalent width of the iron $K\alpha$ line ($\simeq 130 \text{ eV}$) and the large ratio between the 2–10 keV and the [OIII] fluxes. It seems therefore inescapable to conclude that NGC 3147 intrinsically lacks the Broad Line Region (BLR), making it the first “true” Seyfert 2.

Key words: galaxies: active - galaxies: Seyfert - X-rays: individual: NGC3147

1 INTRODUCTION

The basic assumption of Unified Models of Active Galactic Nuclei (AGN) is that type 1 and type 2 objects are intrinsically the same, the apparent difference being solely due to orientation effects (e.g. Antonucci 1993). The absorbing medium assumes the fundamental role in this scenario. It is usually envisaged as an optically thick ‘torus’, embedding the nucleus and the Broad Line Region (BLR). If we observe the torus edge-on, all the nuclear radiation, as well as the broad optical lines coming from the BLR, is completely blocked and we classify the source as a type 2. The narrow lines are still visible, because the Narrow Line Region (NLR) is located farther away from the nucleus, beyond the torus. On the other hand, if the torus does not intercept our line of sight, we observe every component of the spectrum and the object is classified as a type 1.

Simple extrapolations of the optical/UV scenario to the X-ray emission do not, however, always easily fit the observations, leading sometimes to different classifications between the two bands. A larger amount of absorbing material is usually measured from X-ray observations in Seyfert 2s with respect to Seyfert 1s, as expected (e.g. Awaki et al. 1991; Risaliti et al. 1999). However, a number of “true”

Seyfert 2 candidates have been found, i.e. objects with no absorption in the X-rays and no broad optical lines (e.g. Pappa et al. 2001; Panessa & Bassani 2002; Wolter et al. 2005), or with a large intrinsic Balmer decrement of the BLR (Barcons et al. 2003; Corral et al. 2005). The so-called ‘naked’ AGN may be similar objects, being characterised by the absence of broad lines, but strong variability in the optical band (Hawkins 2004) and, apparently, no absorption in the X-rays (Gliozzi et al. 2007). These findings represent a challenge to the Unified Models and may require new classes of objects with intrinsic differences, like the absence of BLR.

Nevertheless, these sources may be highly variable and may change their optical and/or X-ray appearance in different observations. These ‘changing-look’ AGN are not uncommon. In some cases, this behaviour is best explained by a real ‘switching-off’ of the nucleus (see e.g. Matt et al. 2003; Guainazzi et al. 2005), in others by a variable column density of the absorber (e.g. Elvis et al. 2004; Risaliti et al. 2005). If the optical and the X-ray spectrum are taken in two different states of the source, it is clear that the disagreement between the two classifications may be only apparent. Therefore, the key to find genuine ‘unabsorbed Seyfert 2s’ is represented by simultaneous X-ray and optical observations.

NGC 3147 ($z=0.00941$) belongs to the Palomar optical spectroscopic survey of nearby galaxies (Ho et al. 1995). Its classification as a Seyfert 2 is based on both the rel-

* E-mail: bianchi@fis.uniroma3.it (SB)

ative strength of the low-ionization optical forbidden lines with respect to the hydrogen Balmer lines and the ratio of $[\text{OIII}]$ to $\text{H}\beta$, together with the lack of broad permitted lines (Ho et al. 1997a). *ASCA* provided the first X-ray spectrum, which appeared Seyfert 1-like, without significant absorption and a standard powerlaw index (Ptak et al. 1996). The lack of obscuration was later confirmed by *BeppoSAX* (Dadina 2007) and *Chandra*, which also showed that no off-nuclear source can significantly contribute to the nuclear emission (Terashima & Wilson 2003). In order to reconcile the X-ray data with the optical classification, Ptak et al. (1996) suggested that NGC 3147 was a Compton-thick source, given also the relatively large equivalent width (EW) of the iron line. However, this hypothesis was rejected by the use of diagnostic diagrams based on $F_X/F_{[\text{OIII}]}$ and F_X/F_{IR} ratios (Panessa & Bassani 2002). NGC 3147 is, therefore, a genuine candidate to be an unabsorbed Seyfert 2 galaxy. In this paper, we report on simultaneous XMM-*Newton* and optical observations of NCG 3147, in order to settle the issue.

In the following, errors correspond to the 90% confidence level for one interesting parameter ($\Delta\chi^2 = 2.71$), where not otherwise stated. The adopted cosmological parameters are $H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$, $\Omega_\Lambda = 0.73$ and $\Omega_m = 0.27$ (i.e. the default ones in XSPEC 12.3.1).

2 DATA REDUCTION

2.1 XMM-*Newton*

NGC 3147 was observed by XMM-*Newton* on 2006, October 6th (OBSID: 0405020601). The observation was performed with the EPIC CCD cameras, the pn and the two MOS, operated in Large Window and Thin Filter. Data were reduced with SAS 7.0.0 and screening for intervals of flaring particle background was done consistently with the choice of extraction radii, in an iterative process based on the procedure to maximize the signal-to-noise ratio described by Piconcelli et al. (2004). After this process, the net exposure time was of about 14, 16 and 17 ks for pn, MOS1 and MOS2 respectively, adopting extraction radii of 40 arcsec for all the cameras. The background spectra were extracted from source-free circular regions with a radius of 50 arcsec. Pattern 0 to 4 were used for the pn spectrum, while MOS spectra include patterns 0 to 12. Since the two MOS cameras were operated with the same mode, we co-added MOS1 and MOS2 spectra, after having verified that they agree with each other and with the summed spectrum. Spectra were binned in order to oversample the instrumental resolution by at least a factor of 3 and to have no less than 25 counts in each background-subtracted spectral channel. The latter requirement allows us to use the χ^2 statistics. No significant variability is found in the lightcurve of the observation.

2.2 Optical data

NGC3147 was observed at the *Observatorio de Sierra Nevada* (OSN, Granada, Spain) on 2006, October 4th, 5th and 9th. A total of 6 spectra were taken with the spectrograph *Albireo*, with single exposure times of 1800s. The slit width was adjusted to a seeing of ~ 2 arcsec and aligned with the galaxy's major axis. The spectral coverage ranges

from 4000 to 7000 Å, with an average Full Width at Half Maximum (FWHM) spectral resolution of $\sim 4\text{\AA}$, measured from unblended arc lines. No significant spectral variations are present among the spectra but, given the large air masses for the last two days (above 2), we only used the first night spectrum for our analysis (air mass ~ 1.74).

In order to extract the spectrum from the active nucleus with the minimal contamination from the host galaxy, we constructed a spectral template to mimic the latter. We extracted a central spectrum with an aperture width of ~ 1 arcsec. Then, we extracted the host galaxy spectrum ~ 3 arcsec away from the centre and the same aperture as the central spectrum, in order to use it as one of our template ingredients. Möllenhoff (2004) showed that the disk of NGC 3147 has a larger central surface brightness than the bulge, so the bulge is a minor (but significant) component to the host galaxy at the centre. To account for the bulge contribution at the centre, we therefore added to the host galaxy spectrum a reddened elliptical template from the Kinney et al. (1996) atlas. Then, we subtracted the resulting spectrum from the nuclear spectrum so that the absorption bands (G-band, Mg I and Ca I) disappeared.

The subtracted spectrum was finally brought to an absolute flux by scaling it in such a way that the $[\text{OIII}]\lambda 5007$ line flux is in agreement with the value measured by Ho et al. (1997a). Standard reduction techniques were applied, including wavelength calibration against calibrated arc spectrum and an approximate flux calibration using the spectrophotometric standard star G191B2B. There was no attempt, however, to correct for aperture effect, so this calibration is only good in relative terms.

3 DATA ANALYSIS

3.1 XMM-*Newton*

The pn and co-added MOS spectra are well fitted by a simple powerlaw ($\Gamma \simeq 1.6$), absorbed by the Galactic column density ($3.6 \times 10^{20} \text{ cm}^{-2}$; Dickey & Lockman 1990). Local absorption at the redshift of the source is also required by the data, but the column density is very low, being only $(2.8 \pm 1.2) \times 10^{20} \text{ cm}^{-2}$. As shown in the right panel of Fig. 1, it is lower than $5 \times 10^{20} \text{ cm}^{-2}$ at the 99% confidence level for two interesting parameters. An emission line is clearly present, with a resolved line width of $\sigma = 0.27^{+0.28}_{-0.12} \text{ keV}$, a centroid energy of $6.49^{+0.19}_{-0.15} \text{ keV}$ and $\text{EW} = 310^{+190}_{-70} \text{ keV}$. However, the centroid energy and the large σ suggests that this is likely a blend of a neutral iron line and emission from ionised iron, as often found in other Seyfert galaxies (e.g. Bianchi et al. 2005). Indeed, two emission lines, from neutral iron and Fe xxv, are required by the data, at significance of 99.3% and 96%, respectively, according to F-test¹, with EW of around 130 eV for both of them. An upper limit of 70 eV can be derived for a Fe xxvi line. The final fit is as

¹ In principle, the F-test is not a reliable test for the significance of emission lines, but it can be used if their normalizations are allowed to be negative (Protassov et al. 2002).

Table 1. Best fit parameters for the XMM-Newton observation of NGC 3147. Emission lines’ energies were kept fixed.

N_{H} (cm $^{-2}$)	$(2.8 \pm 1.2) \times 10^{20}$
Γ	1.59 ± 0.04
$I_{6.4}$ (ph cm $^{-2}$ s $^{-1}$)	$(2.1 \pm 1.3) \times 10^{-6}$
EW $_{6.4}$ (eV)	130 ± 80
$I_{6.7}$ (ph cm $^{-2}$ s $^{-1}$)	$1.7^{+1.3}_{-1.5} \times 10^{-6}$
EW $_{6.7}$ (eV)	130^{+80}_{-100}
$I_{6.96}$ (ph cm $^{-2}$ s $^{-1}$)	$< 1.1 \times 10^{-6}$
EW $_{6.96}$ (eV)	< 70
$F_{0.5-2 \text{ keV}}$ (cgs)	$(5.7 \pm 0.3) \times 10^{-13}$
$F_{2-10 \text{ keV}}$ (cgs)	$(1.48 \pm 0.07) \times 10^{-12}$
$L_{0.5-2 \text{ keV}}$ (cgs)	$(1.3 \pm 0.1) \times 10^{41}$
$L_{2-10 \text{ keV}}$ (cgs)	$(2.9 \pm 0.1) \times 10^{41}$

good² as the one with a broad line (reduced $\chi^2=1.1$ for 215 d.o.f.): see Fig. 1 and Table 1.

We have also assessed whether the presence of a warm absorber is required by the data. Unfortunately, the RGS spectra have a signal-to-noise ratio too poor to perform any meaningful analysis. We therefore tried to add a simple warm absorber (model ABSOR1³ in XSPEC) to the best fit model of the EPIC spectra. The addition of this component is not required by the data and the value of the ionization parameter ξ is unconstrained. On the other hand, substituting the neutral absorber included in the best fit model with a warm absorber, we find the same column density and $\xi < 0.01$, confirming that the material is neutral.

3.2 Optical data

We measured the line intensities and widths by fitting Gaussian profiles. The results are presented in Table 2, the fitted spectra are in Fig. 2. Line intensities are consistent with what found by Ho et al. (1997a), within errors. The FWHMs have been calculated taking into account the spectrograph spectral resolution. Broad emission line components in the Balmer lines are not required by the data, confirming previous classification of NGC 3147 as a pure Seyfert 2 galaxy. In particular, the upper limit on the broad component of H α implies that its fractional contribution to the total (broad+narrow) H α emission would be at *most* 5%, while the average value in the Ho et al. (1997b) sample is around 60%. Note that the latter is a very conservative estimate, because the sample only includes low-luminosity Seyfert and LINER nuclei, mainly of intermediate type, where the broad component is expected to be much fainter than in bright Seyfert 1s. The lack of broad optical lines in NGC 3147 is therefore an intrinsic property of the source and not an artefact of low signal-to-noise.

We find a value for the Balmer decrement of H α /H β = 8 ± 3 , consistent with the one (~ 5) measured by Ho et al.

² We note that significant residuals are visible around 0.9 keV in the MOS co-added spectrum, as well as the single MOS1 and MOS2 spectra, affecting the quality of the fit. However, they are not present in the higher signal-to-noise-ratio pn spectrum.

³ We are aware that this model oversimplifies the physics of warm absorbers, but here it is used only to assess the presence of absorption by ionised material.

Table 2. Measured line parameters for the optical spectrum of NGC 3147. Line widths for [O III], [N II] and [S II] doublets were fitted by tying down the velocity widths to the same value for each doublet. Values with * were kept fixed.

Line	Flux (10^{-15} cgs)	FWHM (km s $^{-1}$)
H β (narrow)	$2.4^{+0.5}_{-0.7}$	280^{+20}_{-10}
H β (broad)	< 3.8	2000*
[O III] $\lambda 4959$	$5.6^{+0.7}_{-0.5}$	370^{+100}_{-40}
[O III] $\lambda 5007$	17 ± 2	370^{+100}_{-40}
H α (narrow)	20 ± 2	230^{+10}_{-30}
H α (broad)	< 1.1	2000*
[N II] $\lambda 6548$	12 ± 2	410 ± 20
[N II] $\lambda 6583$	56 ± 2	410 ± 20
[S II] $\lambda 6716$	16 ± 2	370^{+40}_{-20}
[S II] $\lambda 6731$	16 ± 2	370^{+40}_{-20}

(1997a). Adopting the latter, the [O III] $\lambda 5007$ corrected flux is $\sim 85 \times 10^{-15}$ erg cm $^{-2}$ s $^{-1}$. Reddening insensitive line ratios as measured from our spectrum are also consistent with those from Ho et al. (1997a): we measure [O III] $\lambda 5007$ /H β = 7 ± 2 and [N II] $\lambda 6583$ /H α 2.8 ± 0.3 , while they measure 6.1 and 2.7, respectively.

4 DISCUSSION

The best fit model for the XMM-Newton spectra is that of a typical type 1 AGN. The amount of neutral column density measured in excess of the Galactic one is of the same order of the latter, and it is therefore fully consistent with being due to the host galaxy’s interstellar medium. The powerlaw index, although somewhat flatter than the average type 1 radio-quiet object, is well within the large dispersion of the hard X-ray Γ distribution (e.g. Piconcelli et al. 2005). The EW of the neutral iron K α line is fully consistent with those typically found in unobscured AGN, especially given its low luminosity (e.g. Bianchi et al. 2007). The only peculiar aspect of its X-ray spectrum is represented by the Fe xxv emission line, whose EW is larger than the one typically arising in a Compton-thin, photoionised gas (see e.g. Bianchi & Matt 2002; Bianchi et al. 2005). However, the line is not statistically very significant and the errors on the EW are quite large (see Sect. 3.1).

To test further the consistency of NGC 3147 being a type 1 AGN, we used the QSO template from Elvis et al. (1994) and scaled it to the X-ray flux measured by our X-ray observation. The predicted continuum level at optical wavelengths is fully consistent with the measured nuclear spectrum. In addition, we have examined the Optical Monitor (Mason et al. 2001) data of our XMM-Newton observation, where the nucleus of NGC 3147 is detected as a point source. Once deconvolved the disk contribution and corrected for Galactic reddening, we get fluxes of (1.81 ± 0.14) and $(0.94 \pm 0.14) \times 10^{-15}$ erg cm $^{-2}$ s $^{-1}$ Å, at 2910 and 2310 Å, respectively, leading to a two-point spectral index $\alpha_{ox} \simeq -1.33^4$, as found for most Seyfert 1s (e.g. Strateva et al. 2005).

⁴ We adopt the original definition by Tananbaum et al. (1979)

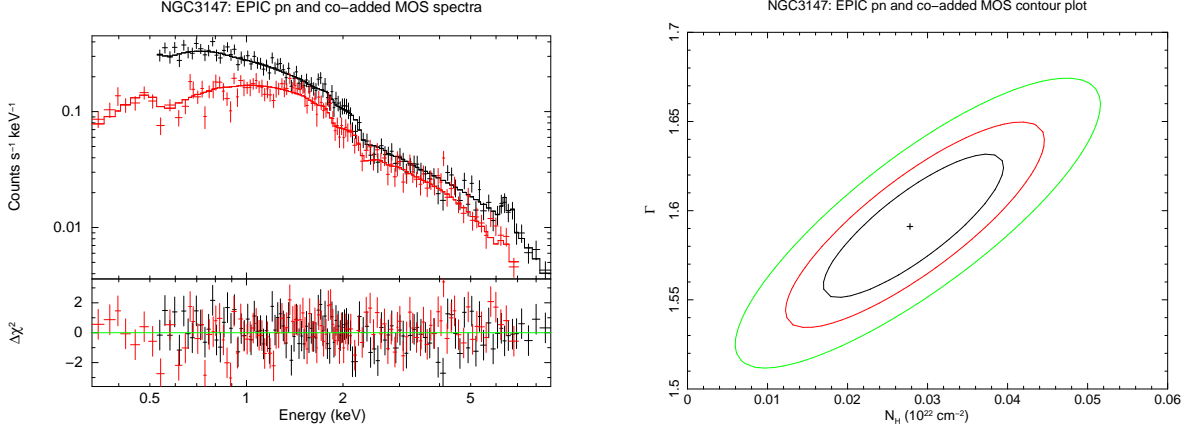


Figure 1. XMM-Newton observation of NGC 3147: *Left panel:* The EPIC pn and co-added MOS spectra, best fit models and $\Delta\chi^2$ deviations. *Right panel:* Photon index vs. column density contour plots at 68, 90 and 99% confidence level for two interesting parameters. The latter parameter does not include Galactic column density, which is fixed as a separate component. See text for details.

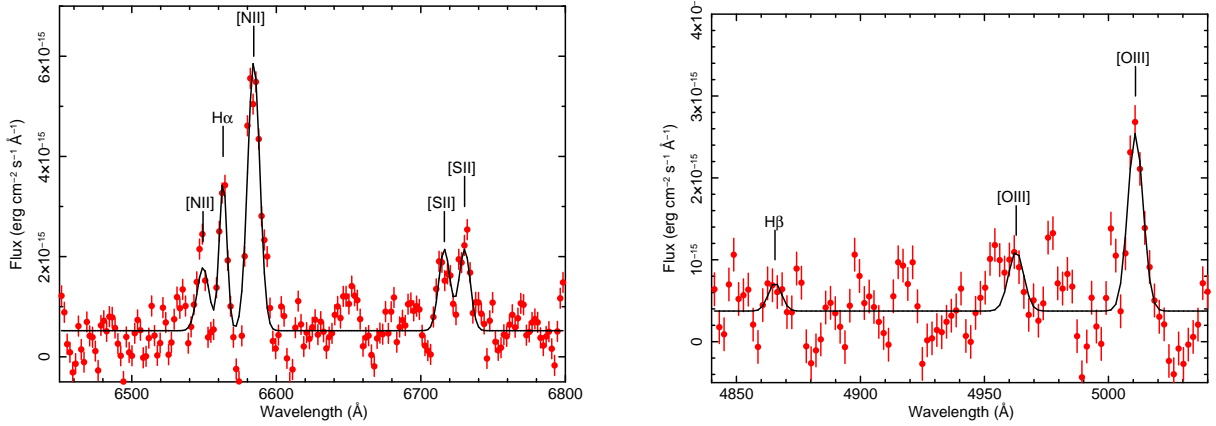


Figure 2. NGC 3147 optical spectrum: $H\alpha$ and $H\beta$ spectral regions along with the best fit model.

However, the analysis of the *simultaneous* optical spectrum presented in this paper confirms the lack of broad permitted lines in this source. The very low column density measured in the X-rays ($N_H < 5 \times 10^{20} \text{ cm}^{-2}$ at the 99% confidence level for two interesting parameters, corresponding to $A_V < 0.3$) is at odds with the large amount of dust required to obscure the BLR. Generally, it is found that any deviation from the Galactic gas-to-dust ratio in AGN always goes in the opposite direction: the obscuration by dust is *lower* than what expected from the associated gas column density (Maiolino et al. 2001). It is difficult to find a physical mechanism able to suppress gas without destroying dust.

If the source were Compton-thick, the lack of X-ray absorption could be apparent, because we would not observe the primary emission at all, but only the reflected light, unaffected by any line-of-sight absorption. This solution is untenable for NGC 3147, because of the EW of the neutral iron line, much smaller than the one expected in the case of a reflection-dominated object ($\approx 1 \text{ keV}$: see e.g. Matt et al.

1996). However, the (relatively) large EW of the FeXXV line may be a signature of reflection from ionised material. In this case, the reprocessed spectrum would be indistinguishable from the primary powerlaw, but an FeXXV EW as low as some hundreds of eV would be likely accompanied by detectable emission from FeXXVI or lower ionised species (see e.g. Bianchi & Matt 2002). This solution would require a rather ad hoc geometry: a Compton-thick neutral absorber blocks the primary emission, while the reprocessed spectrum is instead dominated by an highly ionised material. Moreover, the high ratio between the 2-10 keV and the [OIII] reddening-corrected flux (≈ 20) strongly rejects the hypothesis that we are not directly observing the primary emission (in this case, a ratio lower than 1 is expected: see e.g. Panessa & Bassani 2002, and references therein). Therefore, the source is quite unlikely to be Compton-thick.

The only solution left is that the source intrinsically lacks the BLR. In this respect, it is interesting to note that NGC 3147 has no hidden BLR (HBLR) in polarised light (Tran, private communication). It was shown that HBLR sources are characterized, on average, by larger luminosities than non-HBLR ones (e.g. Gu & Huang 2002). Recently, Elitzur & Shlosman (2006) presented a model which depicts the torus as the inner region of a clumpy wind outflowing

from the accretion disc. A key prediction of this scenario is the disappearance of the BLR at very low bolometric luminosities. Adopting a constant bolometric correction of 20 (Elvis et al. 1994, but any other choice is irrelevant for the present estimate) to the observed X-ray luminosity, the bolometric luminosity of NGC 3147 is about 5×10^{42} erg s⁻¹, which is somewhat larger than the ‘threshold’ calculated by Elitzur & Shlosman (2006) and, in any case, larger than other low-luminosity objects showing broad lines (Ho et al. 1997b). Moreover, the disappearance of the BLR *follows* that of the torus, at lower luminosities. Therefore, their model predicts the absence of the torus in NGC 3147, requiring the strong neutral iron line to be produced in the accretion disc. Current data cannot confirm nor reject this hypothesis.

Another possibility is that the BLR is intimately linked to the accretion rate, rather than the luminosity, of the AGN, being formed in accretion disk instabilities occurring around a critical radius (Nicastro 2000). Below a minimum accretion rate, this radius falls below the innermost stable orbit and the BLR cannot form. We found in the recent literature two estimates for the black hole mass of NGC 3147: $6.2 \times 10^8 M_{\odot}$ (Merloni et al. 2003, inferred from the mass-velocity dispersion correlation) and $2.0 \times 10^8 M_{\odot}$ (Dong & De Robertis 2006, using a mass- K_s bulge luminosity relation). Combined with the above-derived bolometric luminosity, we get a very low Eddington rate for NGC 3147, roughly ranging between 8×10^{-5} and 2×10^{-4} . In any case, this is well below the threshold (around 1×10^{-3}) proposed by Nicastro (2000) and Nicastro et al. (2003), thus supporting this scenario.

In conclusion, it seems inescapable that the key parameter for the observational properties of this source is not orientation, but an intrinsic feature (be it low accretion rate or luminosity), which prevents the BLR to form. NGC 3147 is therefore a “true” Seyfert 2 without the BLR, the first unambiguous component of a new class of AGN which requires to be fitted in a more general Unified Model.

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